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COMPLETE BORE CENTERLINE EXTRACTOR AND SURFACE MAPPER

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Currently, a bore-riding laser target is used to measure gun barrel centerlines. A reference line is established from the center of the breech to the muzzle. The target is positioned at a number of stations down bore and the deviation of the centerline is determined. While accurate, the method requires the average of multiple measurements and physical contact with the barrel. A new measurement device that accurately and quickly finds the entire gun barrel centerline at once is being designed. It consists of an instrumented, sub-caliber, in-bore tube extending the entire length of the barrel. Non-contact displacement gauges are positioned lengthwise on the external surface of the tube. Rotating the in-bore tube provides a map of the surface from which the centerline can be extracted. Flaws in the bore surface and out-of-roundness can also be detected. The proof-of-principle experiments on this new technique are reported here.

INTRODUCTION

During manufacture, every tank gun barrel is measured for straightness, to ensure that it meets a specified tolerance before it is released for field use. Some fielded barrels undergo additional straightness measurements. For instance, since centerlines are known to be a factor in ammunition accuracy, barrels used for ammunition lot acceptance tests have their centerlines re-measured. Likewise, in the field of gun dynamics research, understanding the projectile-barrel interaction requires a knowledge, and therefore an accurate measurement of, the barrel centerline. Measurement of the bore profile has always been both an operational requirement and a useful research tool. Presented in this paper is: a brief description of the current centerline measurement methods, followed by a discussion of the new centerline technique. Next, the centroid finding algorithm is described in some detail. Finally, there is a quick description of what can be found about the bore surface and detection of bore out-of-roundness, followed by the conclusion.

CURRENT MEASUREMENT METHODOLOGY

Currently, laser devices, such as the Gun Tube Inspection Station (GTIS) located at Watervliet Arsenal, and a portable version at Aberdeen Test Center (ATC), are used to measure centerlines. Briefly, a reference line is established from the center of the breech to a bore-riding laser target at the muzzle. The target is positioned at a number of stations down the bore and the deviation of the laser beam from the center of the target is determined. (A more detailed description of techniques for centerline measurements as practiced now and in the past can be found in these references [1]-[5].)

Normally, the centerline is compiled from the average of multiple GTIS measurements. Figure 1 shows a sample centerline in the horizontal plane from three separate passes of ATC's GTIS. The cumulative system error as the target bore rider moves in the barrel is on the order of 0.2mm at the muzzle end. Typically, point-to-point measurements can fluctuate by ± (0.05 to 0.1) mm from one pass to another.

A NEW CENTERLINE MEASUREMENT TECHNIQUE

A new measurement device that accurately and quickly finds the entire bore centerline at once, with minimal physical barrel contact, is being designed. The proposed device (Fig. 2) is an instrumented in-bore sub-caliber tube that extends the entire length of the gun bore. Non-contact (eddy current probe) displacement gauges are positioned lengthwise on the external surface of the tube. Rotating the in-bore tube provides a map of the surface from which the centerline can be extracted. Flaws in the bore surface can also be detected as well as bore out-of-roundness.

The eddy current probe is essentially a small wire coil (usually potted in a non-conductive substrate) through which a high frequency current flows, setting up an electromagnetic field that induces eddy currents in any nearby conductive materials (e.g., metals). The induced current in the conductive specimen creates its own electromagnetic field, counter to the probe/coil field. The electromotive effects of the induced field on the probe circuit can be decoded and used to estimate (precisely) the distance between the probe and the nearby sensed surface. Such probes are sold commercially, and widely used in industry to monitor —for example—machine vibration.

The measurement tube in which the eddy-probe gauges are placed will be a lightweight and extremely stiff composite structure, minimizing its droop. Any remaining bend will be accounted for by calibrating the tube. The tube will be supported at the breech and the muzzle. A servomotor positioned at the breech-end will rotate the tube on bearings. In the first design, the displacement gauges will be located axially every 200mm, with the first station located 230mm from the muzzle. Although more stations could be included or the instrumented tube could be incrementally moved axially (which would provide a more detailed bore map), this set-up will emulate the current GTIS measurement operation.

Diagonal pairs of probes can be used at each measurement station to provide two independent measurements. Probe cables will exit the measurement tube through a hollow shaft at the muzzle end.

CENTERLINE EXTRACTION

Military Specification, MIL-C-13931, [6] defines bend in a machined gun barrel as the deflection, excluding droop, from a theoretical straight line extending between the bore centers at the origin of the bore and at the muzzle end. Droop is the deflection of the tube due to gravity. According to additional specifications for the 120mm, M256 barrel [7], the straightness tolerance for the gun tube is:

> *Overall Straightness:* *The bend, excluding droop, in the bore portion of the tube shall not cumulate over 2mm over the entire bore length.*
> *Incremental Straightness:* *The bend, excluding droop, in the bore portion of the tube shall not exceed 0.5mm in any 600mm interval.*

Figure 3 illustrates the straightness specifications in terms of modem drafting practices [8]. It means that the centerline must lie within a 4.0-mm cylinder for the total bore length and within a 1.0-mm cylinder over any 600-mm length. These are exacting tolerances but the measurement technique must be capable of resolving the centerline with even greater accuracy.

Figure 4 shows a sample bore profile obtained by an eddy current probe and angle encoder at one station with one rotation of the measurement tube. Note, a constant value has been subtracted from all radial measurements to make the deliberately-imposed gouges more prominent in this plot. The center of the bore area, relative to the rotation axis of the tube, is found through an iterative minimization algorithm. In this algorithm, the rotation center serves as the initial estimate for the centroid location assumed at the point (X0=0, Y0=0). The standard deviation of the radius, termed the SigmaRadius, is computed for all the data points in the circumferential direction.

Figure 5 illustrates the minimization technique used for both the horizontal, X, and vertical, Y, planes. The candidate centroid is then shifted a small amount, delta, in the positive and negative directions, both horizontally and vertically. The SigmaRadius is found for each of these new points (X0,Y0+delta), (X0,Y0-delta), (X0+delta,Y0), and (X0-delta,Y0). A quick parabolic fit method finds the point at which SigmaRadius is a minimum (Xmin0,Ymin0) which becomes the starting point for the next iteration (X1= Xmin0,Y1=Ymin0). The process is repeated a number of times until the centroid does not change to any significant degree. Figure 6 shows how quickly the algorithm converges to a fixed point.

Because the algorithm is driving the solution to a minimum, the actual magnitude of the standard deviation is not important. If a large random error creeps into the eddy current probe data or the angle encoder data, the error at each measurement location can be tolerated, because a large number of measurements are taken for each position within the rotation.

Figure 7 shows the centerlines obtained for a short (6") barrel section in the horizontal and vertical planes. The centerline is down and to the right of the rotation axis of the instrumented tube. The error at each measurement station is not additive to the total error and does not accumulate as the bore-riding laser target effect does. These data were acquired several times with more than one eddy current probe. The repeatability is very good. The precision of the measurement is in the range of 0.005 to 0.05 mm, much smaller than the current GTIS error.

BORE SURFACE MAPPING

Figure 8 shows a portion of a bore surface map compared to the actual bore section. The eddy current probes are readily able to detect gouges and missing chrome. The displacement data easily show the machined gouge in the figure. The thickness of the chrome is on the order of 0.1 to 0.2 mm. This too is within the range of accuracy of the displacement guages.

OUT-OF-ROUNDNESS DETERMINATION

Figure 9 shows a greatly exagerated example of how an out-of-round bore would be detected. The radius would appear cyclic as a function of rotation. Also, the standard deviation of the radius would provide a measure of this variability. In this way, the out-of-roundness of the bore could be determined.

CONCLUSIONS

The findings thus far seem to indicate that a device can be built that will find centerlines more easily and accurately than the current laser method. Recent experiments with a short section of an M256 barrel demonstrated that eddy current probes on an instrumented sub-caliber tube could be used to readily map the bore surface. The algorithm used for finding the actual center at a mapped axial position converges quickly to an accurate solution. This device would also have the capabilty to detect flaws such as gouges and missing chrome along the bore surface. In addition, out-of-roundness in the barrel can be determined in the measurement process. Further experiments with a full-scale measurement tube, in an actual gun barrel, are planned.

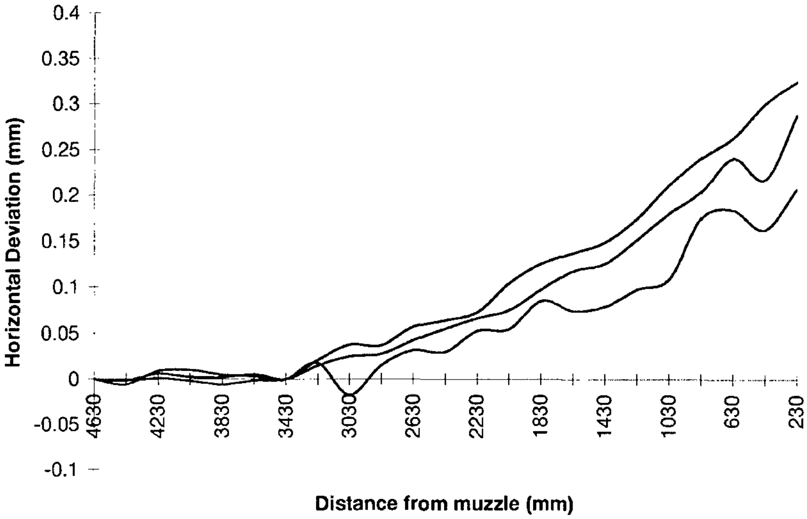

FIGURE 1. Sample Gun Tube Horizontal Centerline, 3 GTIS Measurements.

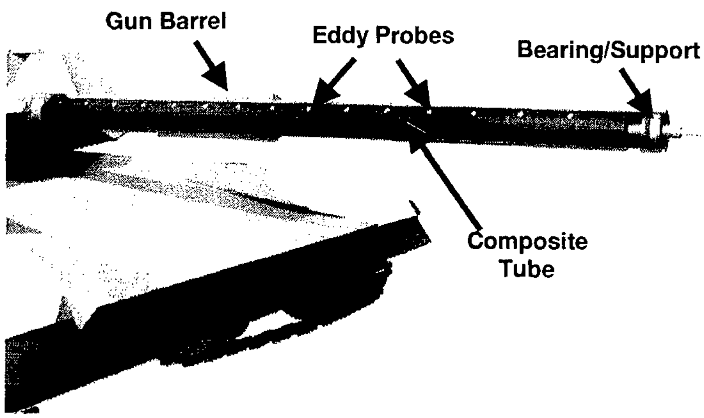

FIGURE 2. Full Bore Centerline Measurement Tube.

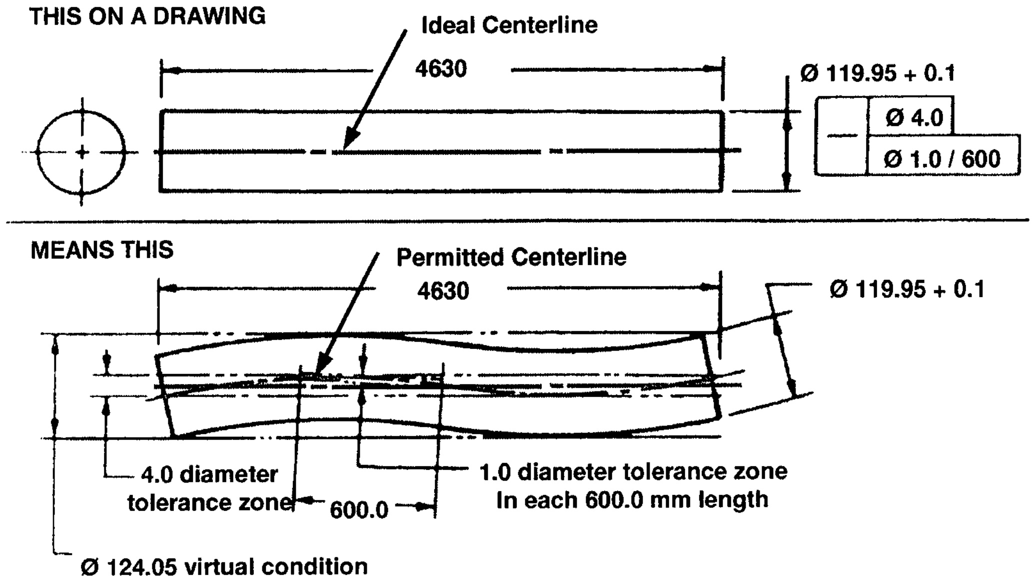

FIGURE 3. Centerline Tolerance Zone.

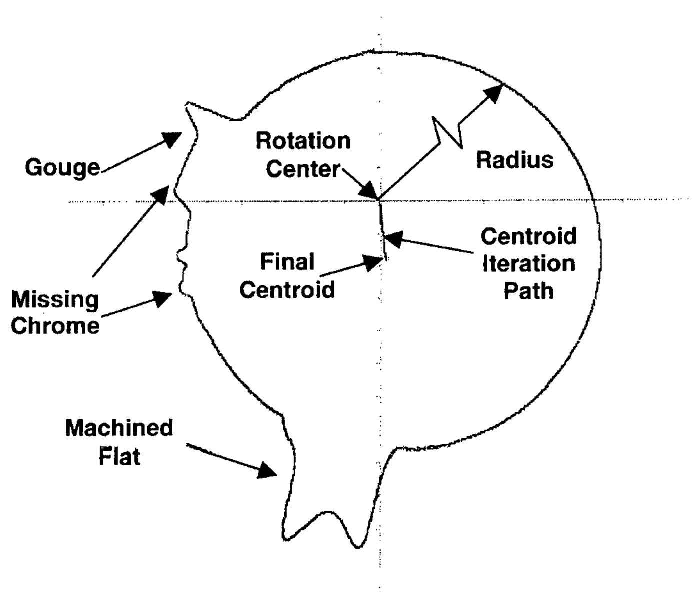

FIGURE 4. Sample Bore Profile.

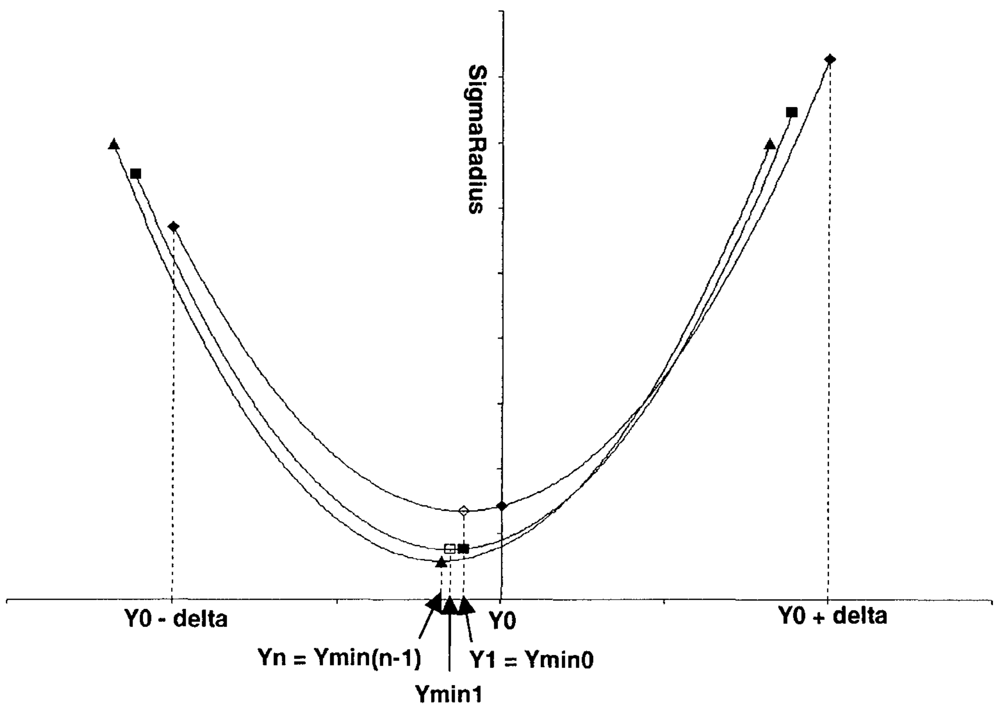

FIGURE 5. Schematic Depiction of the Minimization Technique.

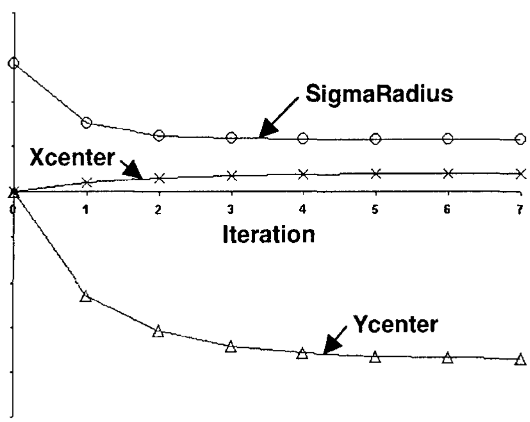

FIGURE 6. Solution of the Centroid Algorithm vs. Number of Iterations.

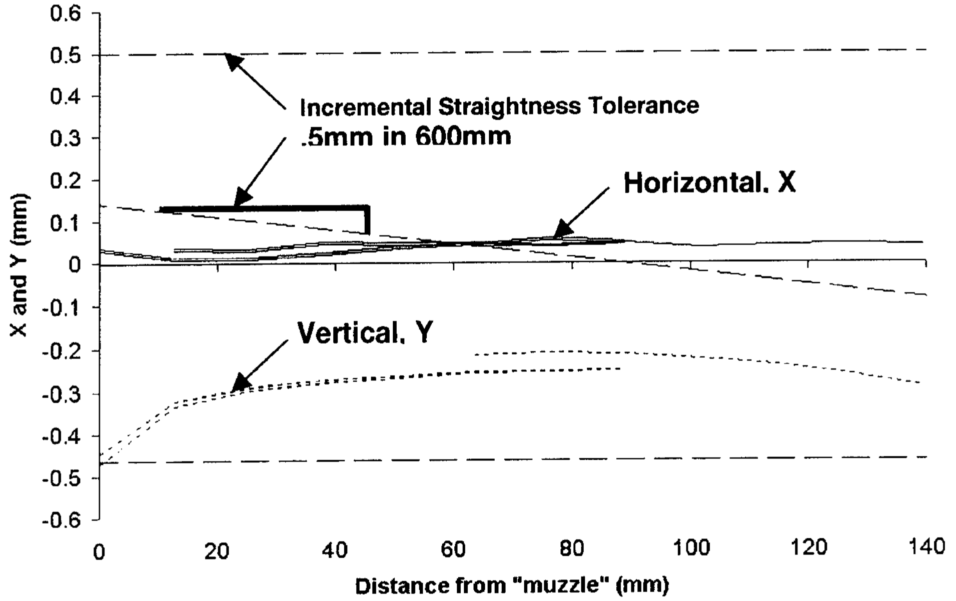

FIGURE 7. Short Gun Tube Section Centerline.

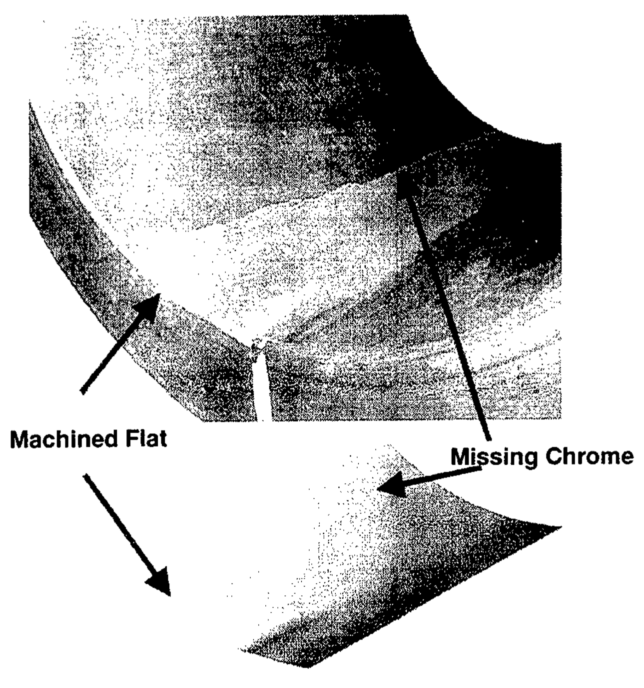

FIGURE 8. Bore Surface Map.

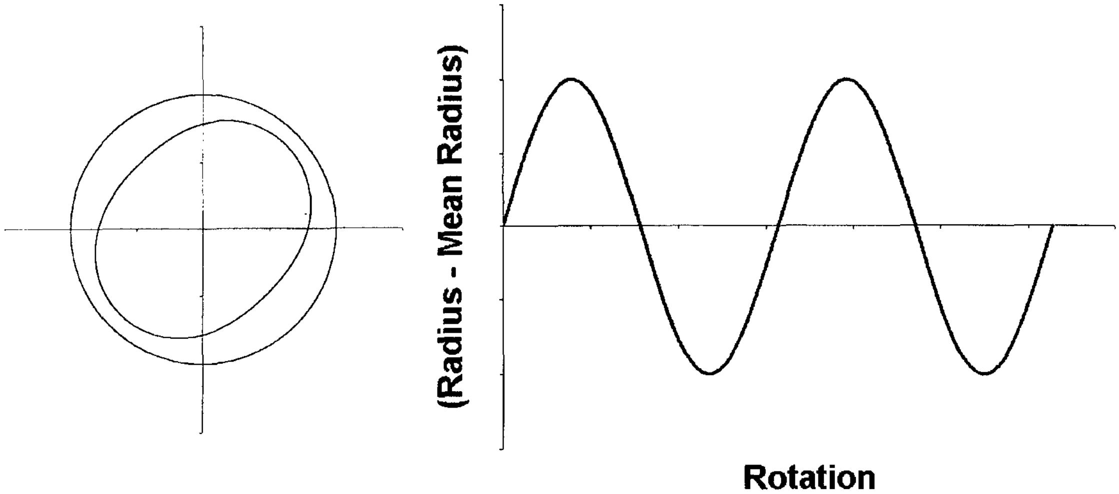

FIGURE 9. Out-of-Roundness.

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